Monitoring Cucumber Beetles in Sweetpotato and Cucurbits with Kairomone-Baited Traps

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ABSTRACT Seven kairomone formulations (Trécé, Inc., Salinas, CA) were evaluated for their effectiveness as attractants for luring three species of cucumber beetles into Pherocon CRW traps (Trécé, Inc.) in cucurbit and sweetpotato fields. The spotted cucumber beetle, *Diabrotica undecimpunctata howardi* Barber; the banded cucumber beetle, *Diabrotica balteata* LeConte; and the striped cucumber beetle, *Acalymma vittatum* (F.), were captured in this study. TRE8276 (TIC mixture: 500 mg of 1,2,4-trimethoxybenzene, 500 mg of indole, and 500 mg of *trans*-cinnamaldeyde) and TRE8336 (500 mg of 1,2,4-trimethoxybenzene, 500 mg of *trans*-cinnamaldeyde, 500 mg of 4-methoxyphenethanol) were the most effective lures for spotted and striped cucumber beetles. None of the kairomone lures was very effective for attracting banded cucumber beetles. Three population peaks of spotted cucumber beetles were observed in cucurbit and sweetpotato fields at the U.S. Vegetable Laboratory (Charleston, SC). The efficacy of TRE8276 declined rapidly after 2 wk in the field. An improved design of the Pherocon CRW trap, with a yellow bottom and more-tapered top section, was more effective for capturing cucumber beetles than the original trap design made entirely of clear plastic. Banded cucumber beetles were not captured in sweetpotato fields at inland locations in North Carolina or South Carolina.

KEY WORDS *Diabrotica undecimpunctata howardi*, *Diabrotica balteata*, *Acalymma vittatum*, *Ipomoea batatas*, Cucurbitaceae

VEGETABLE CROPS IN THE United States are damaged by several species of diabroticite beetles (Coleoptera: Chrysomelidae: Galerucinae: Luperini: Diabroticina), including the cucumber beetles (Krysan 1986, Arnett et al. 2002). The spotted cucumber beetle (or southern corn rootworm), *Diabrotica undecimpunctata howardi* Barber; the banded cucumber beetle, *Diabrotica balteata* LeConte; and the striped cucumber beetle, *Acalymma vittatum* (F.), are the most important diabroticite pests of vegetable crops in the southeastern United States (McKinlay 1992, Capinera 2001). The spotted and banded cucumber beetles each have a wide host range (Arant 1929, Isley 1929, Saba 1970), including cucurbits (Cucurbitaceae) and sweetpotatoes, *Ipomoea batatas* Lam (L.) (Convolvulaceae). However, larvae of the striped cucumber beetle are found primarily on cucurbits (Houser and Balduf 1925).

The chemical ecology of diabroticite beetles has received considerable research attention, and it is believed that these species coevolved with the cucurbits (Metcalf and Lampman 1989b, 1991; Metcalf 1986, 1994). The importance of cucurbitacins as powerful phagostimulants and arrestants has been well documented (Chambliss and Jones 1966, Metcalf et al. 1980). Shaw et al. (1984) reported that a mixture of cucurbitacin and carbaryl killed corn rootworms in traps so that they could be easily counted. However, cucurbitacins are not active as long-range olfactory attractants (Rhodes et al. 1980, Branson and Guss 1983), so volatile components are needed to lure cucumber beetles toward traps or toxic, cucurbitacin-containing baits.

Adult cucumber beetles are attracted to the blossoms of many cucurbit species, where they feed on nectar, pollen, flowers, and developing fruits (Arant 1929, Fisher et al. 1984, Hesler 1998). More than 40 volatile chemicals have been isolated from the flowers of *Cucurbita maxima* (Andersen and Metcalf 1986, 1987, Andersen 1987). Among them are chemically related volatile phenylpropanoids that are produced in large amounts by flowers during pollen maturation and are attractive to adult cucumber beetles (Metcalf and Lampman 1991). A major attractant for the spotted cucumber beetle from *C. maxima* blossoms is (*E*)-cinnamaldehyde (*trans*-cinnamaldehyde) (Metcalf and Lampman 1989a, 1991). Morgan and Crumb (1928) first reported that spotted cucumber beetles were attracted to cinnamic aldehyde and cinnamic alcohol, but they did not associate these chemicals with any host plants. Lampman et al. (1987) also found that several structurally related benzenoid com-

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pounds, including chavicol, phenylacetaldehyde, benzyl acetone, phenethyl alcohol, phenyl acetate, veratrole, methyl eugenol, methyl isoeugenol, eugenol, and isoeugenol, acted as attractants for spotted cucumber beetles. Spotted cucumber beetles were more attracted to phenylacetaldehyde than other species (Lampman et al. 1987). Andersen and Metcalf (1986) found that indole, isolated from the blossoms of *C. maxima* cultivars, was highly attractive to striped cucumber beetles.

A mixture of *Cucurbita* blossom components, 1,2,4-trimethoxybenzene, indole, and *trans*-cinnamaldehyde (TIC mixture), is very attractive to several species of diabroticite beetles, including spotted and striped cucumber beetles (Metcalf and Lampman 1991). Lampman and Metcalf (1987) reported that spotted cucumber beetles also were attracted to a mixture of veratrole, indole, and phenylacetaldehyde (VIP mixture). Relatively minor changes in the makeup of these semiochemical mixtures can radically change the specificity and attractiveness to cucumber beetles (Lampman et al. 1987; Lampman and Metcalf 1987, 1988). Lewis et al. (1990) reported that traps baited with the three-component TIC mixture showed a synergistic effect and captured twice as many striped cucumber beetles as would be expected with the individual components. Banded cucumber beetles have not been evaluated for response to volatile components from cucurbits, even though they aggregate and feed heavily on them (Hesler 1998).

Volatile floral attractants from cucurbits and maize show promise as semiochemicals for monitoring and managing diabroticite beetles (Metcalf and Metcalf 1992, Metcalf 1994). TIC-baited traps have been used to monitor cucumber beetle populations in peanuts, *Arachis hypogaea* L. (Herbert et al. 1996), cucurbits (Cucurbitaceae) (Lewis et al. 1990, Hoffmann et al. 1996), soybean, *Glycine max* (L.) Merr. (Whitworth et al. 2002), and maize, *Zea mays* L. (Lampman and Metcalf 1987). Volatile semiochemicals also might be used to attract and concentrate preovipositional females into fields to complement pest control strategies (Hammack 2003). Volatile attractants also have been tested as an orientation disruption tool for adult western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Wennemann et al. 2001).

Unbaited Pherocon AM sticky traps (Trécé, Inc., Salinas, CA) were suggested as a scouting tool for monitoring adult *Diabrotica* spp. populations and for predicting damage by corn rootworm larvae (Hein and Tollefson 1984, 1985). However, Whitworth et al. (2002) tested a version of the Pherocon CRW kairomone trap (Trécé, Inc.) and found it to be more effective than Pherocon AM or Multigard traps for monitoring corn rootworm populations. Nowatzki et al. (2002) also used Pherocon CRW kairomone traps and found them to be much more efficient than emergence traps for predicting the first day of corn rootworm emergence.

Trécé, Inc., is currently marketing Pherocon CRW kairomone traps and five kairomone lures for monitoring cucumber beetles: Pherocon TR-CRW-M (TRE8275) for Mexican corn rootworm, *Diabrotica virgifera zeae* Krysan & Smith; Pherocon TR-CRW-W

Table 1. Details of cucumber beetle trapping experiments in South Carolina, North Carolina, and Louisiana, 1999–2003

Experiment designation (state-yr)	Field location	County/parrish state	Geographic coordinates	Date exp setup (DOY[a])
SC-1999-A	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	22 Sept. (DOY 265)
SC-1999-B	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	22 Sept. (DOY 265)
SC-2000-A	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	7 June (DOY 159)
SC-2000-B	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	12 June (DOY 164)
SC-2000-C	Duford	Horry Co., SC	(34.20 N, 79.05 W)	15 June (DOY 167)
SC-2000-D	Blackville	Barnwell Co., SC	(33.35 N, 81.30 W)	30 June (DOY 182)
SC-2001-A	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	15 June (DOY 166)
SC-2001-B	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	15 June (DOY 166)
SC-2001-C	Ehrhardt	Bamberg Co., SC	(33.21 N, 81.07 W)	21 June (DOY 172)
SC-2002-A	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	12 June (DOY 163)
SC-2002-B	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	19 June (DOY 170)
SC-2002-C	Hollywood	Charleston Co., SC	(32.72 N, 80.28 W)	5 Aug. (DOY 217)
SC-2002-D	Ehrhardt	Bamberg Co., SC	(33.15 N, 81.10 W)	8 Aug. (DOY 220)
SC-2003-A	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	9 July (DOY 190)
SC-2003-B	USVL	Charleston Co., SC	(32.81 N, 80.07 W)	9 July (DOY 190)
NC-2000-A	Fremont	Wayne Co., NC	(35.56 N, 78.02 W)	25 July (DOY 207)
NC-2001-A	McGee Crossroads and	Johnston Co., NC	(35.52 N, 78.58 W)	4 June (DOY 155)
	Clinton	Sampson Co., NC	(35.02 N, 78.28 W)	4 June (DOY 155)
NC-2001-B	Newton Grove, McGee	Sampson Co., NC	(35.27 N, 78.32 W)	9 July (DOY 190)
	Crossroads, and Clinton	Johnston Co., NC	(35.52 N, 78.58 W)	9 July (DOY 190)
		Sampson Co., NC	(35.02 N, 78.28 W)	9 July (DOY 190)
NC-2001-C	Atchinson's Mill, Hares	Johnston Co., NC	(35.66 N, 78.26 W)	19 July (DOY 200)
	Crossroads, and Narron	Johnston Co., NC	(35.66 N, 78.25 W)	19 July (DOY 200)
		Johnston Co., NC	(35.71 N, 78.24 W)	19 July (DOY 200)
NC-2002-A	Heflin, Stancils Chapel, and	Johnston Co., NC	(35.72 N, 78.20 W)	12 Aug. (DOY 224)
	Kenly	Johnston Co, NC	(35.70 N, 78.20 W)	12 Aug. (DOY 224)
		Johnston Co, NC	(35.63 N, 78.15 W)	12 Aug. (DOY 224)
LA-2001-A	Baton Rouge	E. Baton Rouge, LA	(30.41 N, 91.10 W)	9 July (DOY 190)

[a] Day of the year (Julian date).

(TRE8275) for western corn rootworm; Pherocon TR-CRW-S (TRE8276) for southern corn rootworm (spotted cucumber beetle); Pherocon TR-CRW-N (TRE8391) for northern corn rootworms, *Diabrotica barberi* Smith & Lawrence; and Pherocon TR-CRW-W/N (TRE8391) for mixed populations of western and northern corn rootworms for use in maize pest management (Trécé, Inc. 2003). The purpose of this study was to evaluate the Trécé kairomone lures and Pherocon CRW traps in cucurbit and sweetpotato fields in the southeastern United States.

Materials and Methods

Experiments at the U.S. Vegetable Laboratory (USVL), Charleston, SC. Trapping experiments for cucumber beetles were conducted at the USVL from 1999 to 2003 (Table 1). Each year, the same three fields (0.68, 0.70, and 0.83 ha, separated by at least 200 m) were planted to alternating, adjacent rows of 'Early Summer Crookneck' squash (Seeds by Design, Inc., Maxwell, CA), 'Small Sugar/New England' pumpkin (Hollar Seeds, Rocky Ford, CO), 'Hales Best Jumbo' cantaloupe (Western Hybrid Seed, Inc., Hamilton City, CA), and 'Poinsett 76' cucumber (Dorsing Seeds, Inc., Nyssa, OR). Only one-third of each field was planted on a given planting date. New plantings were made every 3–4 wk to ensure that healthy, flowering plants were present throughout the season. The first planting was made in early April, and the final planting was made in September of each year. Fertilizer (455 kg/ha of 10–10-10) was incorporated into the plant beds. Before planting, metolachlor (Dual II Magnum, Syngenta Crop Protection, Inc., Greensboro, NC) and oryzalin (Surflan A.S., Dow AgroSciences, Indianapolis, IN) were incorporated into the sides, but not the top, of the bedded rows to help control weeds. No insecticides were used. Rows were $\approx$1 m apart, and seeds were planted on $\approx$30-cm centers. Fields were irrigated and cultivated as needed.

Each year, traps also were placed in two sweetpotato fields that were separated by at least 300 m at the USVL. Over the 5 yr of this study, seven different sweetpotato fields were used. They were 0.60, 0.61, 0.75, 0.82, 0.88, 0.92, and 1.10 ha. Fields consisted of mixed plantings of several sweetpotato clones from the sweetpotato breeding program (Dukes et al. 1992). Fertilizer (545–682 kg of 10–10-10) was incorporated into the rows, and fields were planted in June of each year. Soon after planting, metolachlor (Dual II Magnum) was applied for weed control. Sethoxydim (Poast, BASF, Research Triangle Park, NC) was used as needed for control of grasses. During these experiments each year, one of the sweetpotato fields at the USVL was sprayed two to three times with carbaryl (Sevin XLR Plus; Bayer Corporation, Kansas City, MO) as part of the protocols for management of the sweetpotato weevil, *Cylas formicarius elegantulus* (Summers). No insecticides were used on the other fields.

The seven kairomone lures obtained from Trécé, Inc., were TRE8274 (low dose of TIC mixture: 250 mg

Table 1. Continued

Crop	Replicates	Trap design	Times traps checked	Lures evaluated (TRE-)
Cucurbit	2	Old	10	8274, 8275, 8276, 8279, 8282, 8336
Sweetpotato	2	Old	10	8274, 8275, 8276, 8279, 8282, 8336
Sweetpotato	2	Old	39	8274, 8275, 8276, 8279, 8282, 8336, 8391
Cucurbit	2	Old	39	8274, 8275, 8276, 8279, 8282, 8336, 8391
Sweetpotato	2	Old	4	8274, 8275, 8276, 8279, 8282, 8336, 8391
Sweetpotato	2	Old	4	8274, 8275, 8276, 8279, 8282, 8336, 8391
Cucurbit	3	Old & New	56	8276, 8279, 8282, 8336
Sweetpotato	2	Old & New	56	8276, 8279, 8282, 8336
Sweetpotato	3	New	9	8276, 8279, 8282, 8336
Cucurbit	3	Old & New	74	8276, 8279, 8282, 8336, 8391
Sweetpotato	2	Old & New	74	8276, 8279, 8282, 8336, 8391
Sweetpotato	3	New	8	8276, 8279, 8282, 8336, 8391
Sweetpotato	3	New	6	8276, 8279, 8282, 8336, 8391
Cucurbit	3	New	36	8276, 8279, 8282, 8336, 8391
Sweetpotato	2	New	36	8276, 8279, 8282, 8336, 8391
Sweetpotato	2	Old	4	8274, 8276, 8279, 8336, 8391
Sweetpotato	1	New	12	8274, 8275, 8276, 8279, 8282, 8336, 8391
sweetpotato	1	New	12	8274, 8275, 8276, 8279, 8282, 8336, 8391
Sweetpotato	1	New	7	8276, 8336
Sweetpotato	1	New	7	8276, 8336
Sweetpotato	1	New	7	8276, 8336
Sweetpotato	2	New	5	8276, 8336
Sweetpotato	2	New	5	8276, 8336
Sweetpotato	2	New	5	8276, 8336
Sweetpotato	3	New	4	8276, 8336
Sweetpotato	3	New	4	8276, 8336
Sweetpotato	3	New	4	8276, 8336
Sweetpotato	4	New	3	8274, 8275, 8276, 8279, 8282, 8336, 8391

of 1,2,4-trimethoxybenzene, 250 mg of indole, and 250 mg of *trans*-cinnamaldeyde), TRE8275 (500 mg of eugenol and 750 mg of 4-methoxycinnamaldehyde; marketed as Pherocon TR-CRW-W or Pherocon TR-CRW-M), TRE8276 (high dose of TIC mixture: 500 mg of 1,2,4-trimethoxybenzene, 500 mg of indole, and 500 mg of *trans*-cinnamaldeyde; marketed as Pherocon TR-CRW-S), TRE8279 (1,500 mg of eugenol), TRE8282 (750 mg of 4-methoxyphenethanol and 750 mg of 4-methoxycinnamaldehyde), TRE8336 (500 mg of 1,2,4-trimethoxybenzene, 500 mg of *trans*-cinnamaldeyde, 500 mg of 4-methoxyphenethanol), and TRE8391 (750 mg of eugenol and 750 mg of 4-methoxycinnamaldehyde, marketed as Pherocon TR-CRW-N or Pherocon TR-CRW-W/N) (Trécé, Inc. 2003).

Two versions of the Pherocon CRW kairomone trap from Trécé, Inc., were evaluated. The first style of CRW trap was constructed entirely of rigid, clear plastic. It had a cylindrical bottom cup (5.5 in depth, 8 cm in diameter) that snapped onto a top section that was shaped like a truncated cone (8 cm in depth, 13 cm in diameter at bottom and 7 cm in diameter at the top) (illustrated in Whitworth et al. 2002). The bottom cup portion of the trap projected 4 cm into the top section until it engaged three tabs that held it in place. Because of the difference in diameter of the trap sections and because the tabs held them apart, there was an open space around the two portions of the trap that varied from 3 cm at the bottom to 0.5 cm where the sections met. This space allowed insects access into the trap. The specially designed cylindrical kairomone lure dispensers (1.0 by 3.5 cm in diameter) (Trécé, Inc. 2003) were attached by a plastic tab passed through a slit on a flange at the bottom edge of the top portion of the trap so that they hung outside and below the middle of the trap. After the foil lining was removed, the kairomone-impregnated dispenser faced inward toward the open space between the trap sections. At the top of the upper section of the trap there was an indentation that held a cylindrical, toxic-bait pellet (1.2 by 1.3 cm in diameter) containing corn meal, 3.9% carbaryl, and pulverized roots of buffalo gourd, *Cucurbita foetidissima* H.B.K. (Trécé, Inc. 2003). This bait pellet was used to attract and kill cucumber beetles that entered the trap. In addition to cucurbitacins, buffalo gourd root powder also contains volatile attractants that further enhance feeding by *Diabrotica* larvae (Cossé and Baker 1999). Cucurbitacins themselves are not volatile attractants of cucumber beetles (Rhodes et al. 1980, Branson and Guss 1983). The bottom portion of the trap had a cylindrical indentation (2 cm in depth, 2.3 cm in diameter) for the attachment of a piece of PVC rigid conduit (2.3 cm in diameter). These support poles were 60 cm in length and sharpened so they could be pushed into the ground. An improved version of the Pherocon CRW trap, now being marketed (Trécé, Inc. 2003), was evaluated in 2001 and 2002. This improved trap, which we will refer to as the new trap design, had a cylindrical bottom portion identical to the old design except that it was colored bright yellow. The upper portion of the new design was similar to the original design except that the top or roof of the trap was tapered instead of flat, which was intended to direct the trapped beetles toward the cucurbitacin-containing toxic bait at the peak. Each type of trap was positioned, baited, and checked in the same way in the field.

Traps were placed within rows of cucurbits and in open spaces between plots of sweetpotatoes at the USVL. In 2001 and 2002, old and new trap designs were compared for each kairomone lure. In 1999 and 2000, only the old trap design was used, and in 2003 only the new trap design was tested. Each field was designated as a replication in a randomized complete block design. Traps were checked and beetles removed two to three times per week (Table 1). Lures were changed every 2 wk, and the lures were assigned randomly to new trap positions at that time. Data were analyzed by analysis of variance (ANOVA) using PROC GLM, and treatment means were separated by Fisher least-significant difference (LSD) test ($P < 0.05$) (SAS Institute 1989).

Experiments at Other Locations. Trapping experiments were conducted at five other field locations in South Carolina during 2000–2003. Experiments were set up as randomized complete block designs with two to three replications, and traps were checked four to nine times on an irregular basis (Table 1). Lures that had been in the field for at least 2 wk were changed at the time the traps were checked. Lures were assigned randomly to new trap positions each time they were changed. In 2000, Pherocon CRW traps (old design) with all seven Trécé lures were set up in a grower's sweetpotato field near Duford, and in a sweetpotato field at the Clemson University's Edisto Research and Education Center, Blackville, SC. In 2001, traps (new design) with four Trécé lures (TRE8276, TRE8279, TRE8282, and TRE8336) were set up in a cooperating grower's sweetpotato field near Ehrhardt, SC. In 2002, traps (new design) with five Trécé lures (TRE8276, TRE8279, TRE8282, TRE8336, and TRE8391) were placed in a sweetpotato field at a different location near Ehrhardt, and in a cooperating grower's sweetpotato field in Hollywood, SC. Except for the Duford site in 2000, no insecticides were applied to these fields. At Duford, cultural practices were at the grower's discretion; a preplant insecticide application of chlorpyrifos (Lorsban 15G, Dow AgroSciences) was made, but no foliar insecticides were applied.

Trapping experiments were conducted at 11 field locations in North Carolina during 2000–2002 (Table 1). The old design of the Pherocon CRW kairomone trap was used in 2000, whereas the new design was used for 2001 and 2002 tests. Experiments were set up in randomized complete block designs, and traps were checked four to 12 times each year (Table 1). Lures that had been in the field for at least 2 wk were changed at the time the traps were checked. Lures were assigned randomly to trap positions each time they were changed. Cultural practices, including preplant insecticide applications, were at the growers'

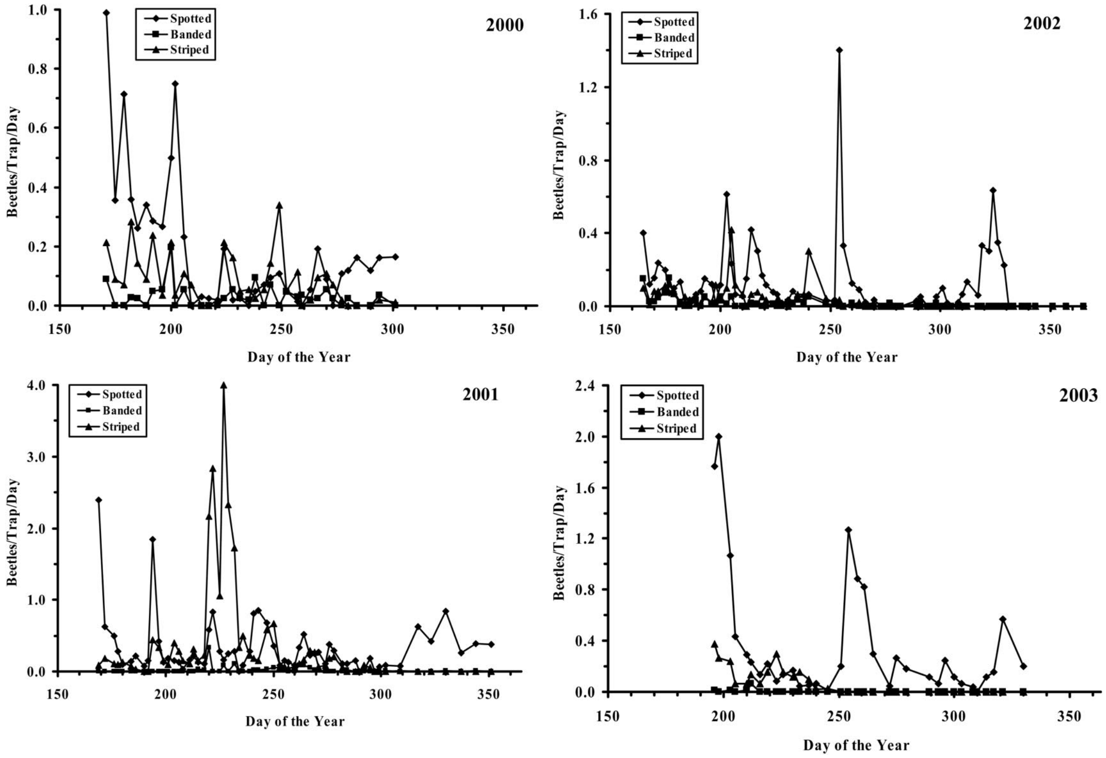

Fig. 1. Average number of spotted, striped, and banded cucumber beetles captured in Pherocon CRW traps baited with kairomone lures (Trécé, Inc.) for 4 yr (2000–2003) in cucurbit fields at the U.S. Vegetable Laboratory, Charleston, SC.

discretions. In 2000, traps were set up with two replications of five Trécé lures (TRE8274, TRE8276, TRE8279, TRE8336, and TRE8391) in a grower's sweetpotato field near Fremont, NC. In 2001, three trapping experiments were conducted in North Carolina. For the first 2001 experiment (NC-2001-A, Table 1), traps were set up in sweetpotato fields at the North Carolina State University's Clinton Research Station and near McGee Crossroads, NC. For the second 2001 experiment (NC-2001-B), traps were placed in sweetpotato fields near McGee Crossroad, at the Clinton Research Station, and near Newton Grove, NC. For the third 2001 experiment (NC-2001-C), traps were set up in sweetpotato fields near Atchinson's Mill, Hares Crossroads, and Narron, NC. In 2002, traps were placed in sweetpotato fields near Heflin, Stancils Chapel, and Kenly, NC.

In 2001, an experiment with Pherocon CRW kairomone traps (new design) was set up in randomized complete block design with all seven Trécé lures in a sweetpotato field at the Louisiana State University AgCenter, Burden Research Plantation in Baton Rouge, LA (Table 1). Traps were checked three times. Lures were changed and assigned randomly to new field positions on 29 July. Typical cultural practices for sweetpotatoes were used during this trapping period, but no insecticides were applied during this period.

Lure Aging Experiment, 2001. To be useful for integrated pest management (IPM) programs, semiochemical lures must be active in the field for an extended period of time, and the controlled release of active components is critical to the lure's functionality (Kydonieus and Beroza 1982). Eventually, most of the attractant chemicals are released from the lure and it becomes ineffective. Therefore, in 2001, we conducted an experiment to test the effective field life of one of the Trécé kairomone lures (TRE8276). On 11 June, lures were opened (foil seal removed) and clipped hanging downward (in the same position as they would be if attached to a trap) to an unsheltered rack in a field at the USVL. Lures were aged in this way for 0, 1, 2, 3, 4, 5, 6, 7, or 8 wk. Weather conditions were typical for late June and July in Charleston, with hot, humid, sunny, or partly cloudy days, and occasional brief afternoon rain showers. Minimum temperatures-maximum temperatures and rainfall for the lure-aging period were week 1, 21–34°C, 28 mm; week 2, 17–32°C, 104 mm; week 3, 20–32°C, 20 mm; week 4, 21–33°C, 66 mm; week 5, 18–36°C, 5 mm; week 6, 18–34°C, 20 mm; week 7, 21–32°C, 107 mm; and week 8, 19–31°C, 8 mm. After lures had been aged, they were placed into zip-lock plastic bags and put into a freezer (−17.8°C) until needed for the field experiment. On 6 August, Pherocon CRW kairomone traps (new design) were placed into the three USVL cucurbit fields described above. Lures of each age classification were set up in a randomized complete block design with each field representing one replication. Traps were checked and beetles were removed nine times (every 2–3 d) over a 3-wk period. After the first week and after the second

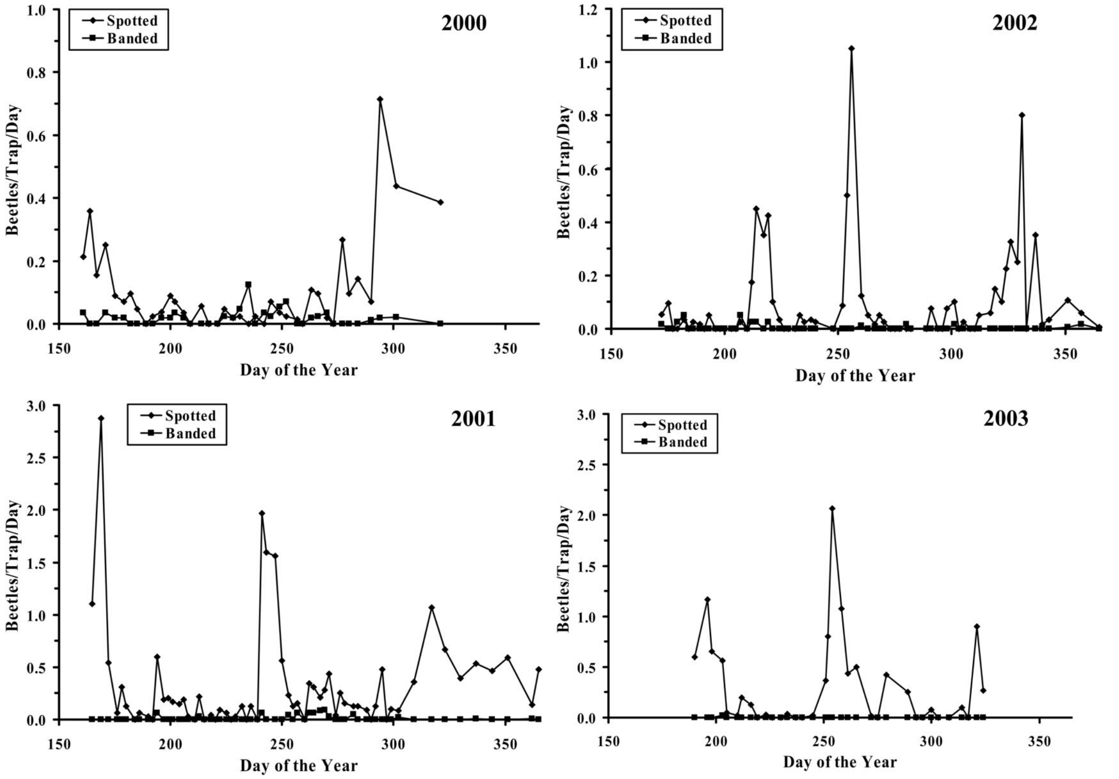

Fig. 2. Average number of spotted and banded cucumber beetles captured in Pherocon CRW traps baited with kairomone lures (Trécé, Inc.) for 4 yr (2000–2003) in sweetpotato fields at the U.S. Vegetable Laboratory, Charleston, SC.

week, a new 0-age lure was added to the experiment, and the age designations of the lures in the field were advanced 1 wk. Therefore, by the end of the experiment, there were 10 lure-age treatments in each field classified as 0–1, 1–2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–8, 8–9, and 9–10 wk old. Data were analyzed by ANOVA, and differences among means (adult cucumber beetles per trap per day) for the lure-age treatments were separated by Fisher's LSD test ($P < 0.05$) (SAS Institute 1989).

Results

Experiments at the USVL, Charleston, SC. Over the 5-yr period (1999–2003) of experiments at the USVL, 2,661 spotted cucumber beetles were captured in cucurbits and 1,780 were captured in sweetpotatoes. The kairomone trapping system evaluated in this study clearly delineated population peaks of spotted cucumber beetles in cucurbit and sweetpotato fields. In 2001, 2002, and 2003, there were three distinct population peaks of spotted cucumber beetles in cucurbits (Fig. 1) and sweetpotatoes (Fig. 2) at the USVL. In 2000, the midsummer peak of spotted cucumber beetles was indistinct (Figs. 1 and 2). This observation of three population peaks for spotted cucumber beetles is in agreement with studies from other locations with similar warm climatic conditions as coastal South Carolina (Arant 1929, Michelbacher et al. 1955).

TRE8276 and TRE8336 were the best attractant lures for spotted cucumber beetles in this study (Tables 2 and 3). TRE8274, a dilution of TRE8276, was also effective. In cucurbits, TRE8276-baited traps captured significantly more spotted cucumber beetles than did TRE8336-baited traps in 2002, but these two lures worked equally well the other years (Table 2). In sweetpotato, TRE8336-baited traps captured significantly more spotted cucumber beetles than did TRE8276-baited traps in 2000, 2001, and 2003, but these lures worked equally well in 1999 and 2002 (Table 3). None of the other Trécé lures were very effective for trapping spotted cucumber beetles (Tables 2 and 3).

Over the 5-yr period, 1,047 striped cucumber beetles were captured in cucurbit fields at the USVL. No distinct population peaks of striped cucumber beetles were seen in 2000. However, in 2001, there was a single large population peak in August (Fig. 1). In 2002 and 2003, there were distinct population peaks of striped cucumber beetles in cucurbits in July and in August (Fig. 1). Each year, TRE8276-baited traps captured significantly more striped cucumber beetles than did traps baited with the other lures (Table 2). As expected, few (58) striped cucumber beetles were captured in sweetpotato fields at the USVL. Most of these

Table 2. Season-long captures of three species of cucumber beetles by seven Trécé kairomone lures in Pherocon CRW kairomone traps in fields of mixed cucurbits, Charleston, SC, 1999–2003

Lure	Beetles/trap/d[a]					
	1999	2000	2001	2002	2003	Avg
			Spotted cucumber beetle			
TRE8274	0.245ab	0.247bc				0.246
TRE8275	0.078b	0.045d				0.062
TRE8276	0.377a	0.498a	0.462a	0.267a	0.833a	0.487
TRE8279	0.042c	0.044d	0.106b	0.052c	0.059b	0.051
TRE8282	0.250ab	0.065d	0.154b	0.088c	0.178b	0.147
TRE8336	0.375a	0.372ab	0.536a	0.188b	0.631a	0.420
TRE8391		0.108cd		0.051c	0.142b	0.100
			Banded cucumber beetle			
TRE8274	0.108 ns[b]	0.027abc				0.068
TRE8275	0.147	0.017bc				0.082
TRE8276	0.236	0.059a	0.034a	0.022 ns	0.002 ns	0.071
TRE8279	0.158	0.042ab	0.009b	0.017	0.012	0.048
TRE8282	0.108	0.003c	0.011b	0.011	0.000	0.027
TRE8336	0.092	0.021bc	0.002b	0.012	0.000	0.025
TRE8391		0.037abc		0.018	0.002	0.019
			Striped cucumber beetle			
TRE8274	0.146ab	0.166b				0.156
TRE8275	0.000b	0.007c				0.004
TRE8276	0.237a	0.377a	0.569a	0.131a	0.184a	0.300
TRE8279	0.000b	0.003c	0.047b	0.010b	0.022b	0.016
TRE8282	0.000b	0.012c	0.031b	0.012b	0.059b	0.023
TRE8336	0.017b	0.030c	0.087b	0.019b	0.054b	0.041
TRE8391		0.013c		0.010b	0.021b	0.015

[a] For each beetle species, means within columns followed by a common letter are not significantly different ($P = 0.05$, Fisher's least significant difference).
[b] Nonsignificant F value in AVOVA.

Table 3. Season-long captures of three species of cucumber beetles by seven Trécé kairomone lures in Pherocon CRW kairomone traps in sweetpotato fields, Charleston, SC, 1999–2003

Lure	Beetles/trap/d[a]					
	1999	2000	2001	2002	2003	Avg
			Spotted cucumber beetle			
TRE8274	0.033 ns[b]	0.151b				0.092
TRE8275	0.000	0.029c				0.015
TRE8276	0.059	0.159b	0.394b	0.204a	0.374b	0.238
TRE8279	0.025	0.020c	0.117c	0.046b	0.048c	0.051
TRE8282	0.067	0.057c	0.148c	0.060b	0.106bc	0.088
TRE8336	0.125	0.276a	0.592a	0.154a	0.764a	0.382
TRE8391		0.040c		0.023b	0.097bc	0.053
			Banded cucumber beetle			
TRE8274	0.133 ns	0.022 ns				0.078
TRE8275	0.150	0.003				0.077
TRE8276	0.000	0.019	0.012 ns	0.008 ns	0.000 ns	0.008
TRE8279	0.275	0.014	0.016	0.007	0.003	0.063
TRE8282	0.292	0.003	0.004	0.002	0.000	0.060
TRE8336	0.067	0.037	0.015	0.001	0.000	0.024
TRE8391		0.029		0.004	0.000	0.011
			Striped cucumber beetle			
TRE8274	0.000 ns	0.003 ns				0.002
TRE8275	0.000	0.000				0.000
TRE8276	0.050	0.003	0.057a	0.000 ns	0.000 ns	0.022
TRE8279	0.000	0.000	0.011b	0.000	0.003	0.003
TRE8282	0.000	0.000	0.010b	0.000	0.000	0.002
TRE8336	0.000	0.000	0.014b	0.002	0.000	0.003
TRE8391		0.000		0.002	0.000	0.001

[a] For each beetle species, means within columns followed by a common letter are not significantly different ($P = 0.05$, Fisher's least significant difference).
[b] Nonsignificant F value in AVOVA.

were captured in 2001, probably due to the proximity of this sweetpotato field to a cucurbit field (Table 3).

Only 218 banded cucumber beetles were captured in cucurbits and 124 were captured in sweetpotatoes at the USVL, 1999–2003. No distinct population peaks of banded cucumber beetles could be determined for any year at the USVL. Adult banded cucumber beetles were sometimes seen on sweetpotato and cucurbit foliage, but many more spotted cucumber beetles were observed. For the most part, there were no significant differences among lure treatments for season-long captures of banded cucumber beetles (Tables 2 and 3). However, in 2000 and 2001 in cucurbits, TRE8276-baited traps captured significantly more banded cucumber beetles than did traps baited with the other lures (Table 2). Nevertheless, none of the kairomone lures distinguished itself as being especially attractive to banded cucumber beetles. Given this species' habit of frequenting cucurbit flowers, additional floral volatiles should be evaluated for use in Pherocon CRW kairomone traps.

Experiments at Other Locations. The spotted cucumber beetle was the dominant species captured (6,190 beetles) by using kairomone-baited Pherocon CRW traps in sweetpotato fields at all locations in 2000–2002 (Table 4). Only 19 banded cucumber beetles were captured at the Louisiana location, and a single banded cucumber beetle was collected at the Ehrhardt, SC, site in 2002. Only 11 striped cucumber beetles were captured at two sites in North Carolina in 2000 and 2001 (Table 4).

For these locations, the effectiveness of the seven Trécé lures for capturing spotted cucumber beetles was similar to the results from sweetpotato at the USVL (Tables 3 and 4). Overall at locations other than the USVL, TRE8336-baited traps captured more spotted cucumber beetles than did TRE8276-baited traps in three of 11 experiments, but these lures were equally effective in the other eight experiments in sweetpotatoes (Table 4).

Trap Design. Overall, the new version of the Pherocon CRW kairomone trap was an improvement over the old design (Fig. 3). Increased trap captures with the new trap design were most evident for striped cucumber beetles in cucurbits, where treatment differences were significant both years (2001, $P = 0.005$; 2002, $P = 0.013$). For spotted cucumber beetles in 2001, the new trap design captured significantly more beetles than the old design in cucurbits ($P = 0.004$) and sweetpotatoes ($P = 0.030$). However, there were no significant differences in trap design in 2002 for spotted cucumber beetles (cucurbits, $P = 0.095$; sweetpotatoes, $P = 0.349$) (Fig. 3). The new trap design caught significantly more banded cucumber beetles in cucurbits ($P = 0.017$), but not in sweetpotato ($P = 0.937$) in 2002. Trap design was not significant for banded cucumber beetles in either cucurbits ($P = 0.854$) or sweetpotato ($P = 0.263$) in 2001 (Fig. 3).

Lure Aging Experiment, 2001. The age of TRE8276 lures significantly affected trap captures of spotted ($F_{11,219} = 7.8$; $P < 0.0001$) and striped ($F_{11,219} = 8.2$;

Table 4 Cucumber beetle adults captured with seven Trécé lures in Pherocon CRW traps in sweetpotato fields in South Carolina, North Carolina, and Louisiana, 2000–2002

Lure	Blackville, SC, 2000	Duford, SC, 2000	Fremont, NC, 2000	Ehrhardt, SC, 2001	Johnston Co., NC, 2001	John./Sam., NC,[a] 2001	John./Sam., NC,[a] 2001	LA, 2001	Ehrhardt, SC, 2002	Hollywood, SC, 2002	Johnston Co., NC, 2002	Avg
	Spotted cucumber beetles/trap/d[b]											
TRE8274	0.14ab	1.47a	0.95b	—[c]	—	0.78ab	—	8.40ab	—	—	—	2.35
TRE8275	0.00c	0.20b	—	—	—	0.17b	—	1.30d	—	—	—	0.42
TRE8276	0.03bc	1.18ab	0.92b	0.54a	3.05ns[d]	0.66ab	0.98ns	6.50bc	0.53a	0.05ab	4.78ns	1.75
TRE8279	0.00c	0.04b	0.14c	0.01b	—	0.11b	—	1.40d	0.01b	0.01b	—	0.22
TRE8282	0.00c	0.10b	—	0.02b	—	0.29ab	—	3.80cd	0.15b	0.01b	—	0.62
TRE8336	0.15a	1.49a	1.61a	0.26ab	4.39	1.10a	2.05	11.20a	0.40a	0.10a	2.97	2.33
TRE8391	0.00c	0.14b	0.31c	—	—	0.29ab	—	1.90d	0.02b	0.01b	—	0.38
	Total no. of cucumber beetles collected											
Spotted	41	486	237	200	2120	416	362	408	300	40	1580	
Banded	0	0	0	0	0	0	0	19	1	0	0	
Striped	0	0	1	0	10	0	0	0	0	0	0	

[a] Johnston and Sampson counties, North Carolina, 2001.
[b] Means within columns followed by a common letter are not significantly different ($P = 0.05$, Fisher's least significant difference).
[c] Kairomone lure not evaluated.
[d] Nonsignificant F value in AVOVA.

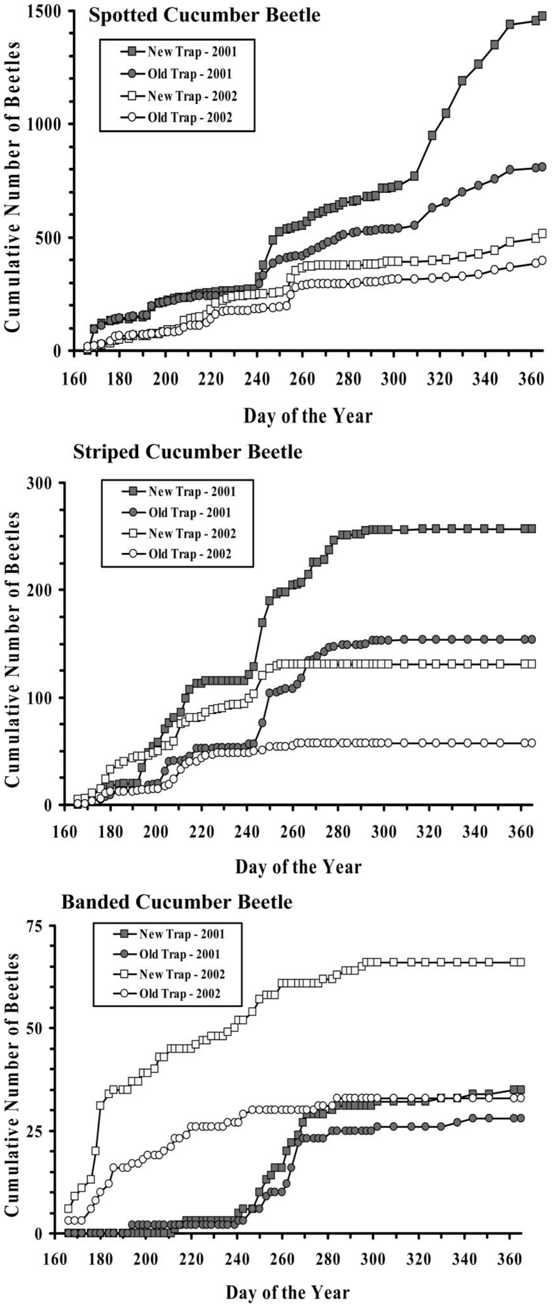

Fig. 3. Cumulative numbers of spotted, striped, and banded cucumber beetles captured by two versions (old and new) of Pherocon CRW traps (Trécé, Inc.) in cucurbit and sweetpotato fields at the U.S Vegetable Laboratory, Charleston, SC, 2001–2002.

$P < 0.0001$) cucumber beetles in mixed cucurbit plantings (Table 5). However, there were no significant differences ($F_{11,219} = 1.6$; $P = 0.095$) in captures of banded cucumber beetles, which were trapped in low numbers (22 beetles) during the 3 wk of this experiment. TRE8276 lost considerable activity after 2 wk of aging in the field, but after 10 wk, some beetles were still captured in the Pherocon CRW kairomone traps (Table 5). Although more striped cucumber beetles (321 beetles) were captured during this experiment, the effects of lure age affected spotted (76 beetles) in a similar manner. This experiment clearly shows that TRE8276 lures should be changed at least every 2 wk in the field.

Table 5. Captures of three species of cucumber beetles in Pherocon CRW kairomone traps baited with TRE8276 kairomone lure that had been aged for 0–10 wk before being evaluated in fields of mixed cucurbits, Charleston, SC, 2001

Age of lure (wk)	Beetles/trap/d ± SE[a]		
	Striped cucumber beetle	Spotted cucumber beetle	Banded cucumber beetle
0–1	3.09 ± 0.83a	0.72 ± 0.22a	0.11 ± 0.07 ns[b]
1–2	2.94 ± 1.04a	0.35 ± 0.09b	0.09 ± 0.06
2–3	0.60 ± 0.14b	0.24 ± 0.06bc	0.04 ± 0.03
3–4	0.49 ± 0.14b	0.08 ± 0.04d	0.02 ± 0.02
4–5	0.36 ± 0.17b	0.10 ± 0.05cd	0.01 ± 0.01
5–6	0.47 ± 0.15b	0.16 ± 0.05cd	0.10 ± 0.05
6–7	0.22 ± 0.07b	0.06 ± 0.03d	0.00 ± 0.00
7–8	0.20 ± 0.07b	0.09 ± 0.04d	0.07 ± 0.04
8–9	0.15 ± 0.06b	0.02 ± 0.02d	0.02 ± 0.02
9–10	0.06 ± 0.04b	0.04 ± 0.03d	0.00 ± 0.00

[a] For each beetle species, means within columns followed by a common letter are not significantly different ($P = 0.05$, Fisher's least significant difference).

[b] Nonsignificant F value in AVOVA.

Discussion

Pherocon CRW traps baited with Trécé kairomone lures provide an effective trapping system for spotted and striped cucumber beetles in cucurbits and sweetpotatoes. Because TRE8274, TRE8276, and TRE8336 have 1,2,4-trimethoxybenzene and *trans*-cinnamaldeyde in common, their attractiveness to spotted and striped cucumber beetles is most likely due to these components. This result is consistent with previous reports on the attraction of spotted and striped cucumber beetles (Metcalf and Lampman 1989a, 1991). However, none of the other four Trécé lures had either 1,2,4-trimethoxybenzene or *trans*-cinnamaldeyde, and they were much less attractive to cucumber beetle adults.

The new design of the Pherocon CRW trap was an improvement over the original design. Because more than one improvement was made to the trap design, it was not possible to determine exactly why the new trap worked better than the old one. However, it is likely that the new yellow bottom had more of an effect on trap captures than did the slight improvement in shape of the top portion of the trap. This is because yellow attracts cucumber beetles from a distance (Hesler and Sutter 1993), whereas the improved top portion acts simply to direct the beetles to the insecticide bait.

Because larvae are seldom found when sweetpotato roots are dug, injury often cannot be attributed to a particular cucumber beetle species. In fact, it is even difficult to determine whether root injury was caused by wireworms (W), cucumber beetles (*Diabrotica* sp. [D]), or flea beetles (*Systena* sp. [S]), so damage by these pests is often lumped into a single category called WDS (Schalk et al. 1991). Observed WDS damage could be due to one or more of these pests, including a combination of cucumber beetle species. Clearly, additional tools, such as Pherocon CRW kairomone traps that could identify what cucumber beetles were present, would be useful for making pest management decisions for sweetpotatoes.

Elsey (1988) found that the spotted cucumber beetle was numerically dominant over the banded and striped cucumber beetle in coastal South Carolina. The spotted cucumber beetle was also the most abundant species trapped in cucurbits and sweetpotatoes at the USVL during the current study. This species also predominated at all of the upstate South Carolina and North Carolina sweetpotato locations we examined.

Our data support the conclusions of Houser and Balduf (1925) that the striped cucumber beetle is primarily a pest of cucurbits, and not sweetpotatoes. This species is not listed as a pest of sweetpotatoes in state sweetpotato production guides, except for Virginia (Tuckey et al. 2001). We captured few striped cucumber beetles in sweetpotatoes, although sizable populations were trapped nearby in cucurbits. The striped cucumber beetle is a more-northerly species, and it is found in fewer numbers in the southeastern United States (Houser and Balduf 1925, Isley 1927).

Our data also show that the banded cucumber beetle is not present in the major sweetpotato production areas of North Carolina and South Carolina and that the primary cucumber beetle pest on sweetpotato in these areas is the spotted cucumber beetle. However, the banded cucumber beetle is a major pest of sweetpotatoes in Louisiana (Pitre and Kantack 1962). Since ≈1900, the banded cucumber beetle has expanded its range from southern Texas eastward to the coastal areas of the Gulf of Mexico and Atlantic Ocean up to North Carolina (Smith 1966, Krysan and Branson 1983). Banded cucumber beetles are generally confined to the coastal areas of South Carolina, usually no >65 km from the coast (Clemson University 2003). However, the distribution map published by Krysan (1986) shows banded cucumber beetles distributed further inland in South Carolina and North Carolina.

The northern range of the banded cucumber beetle is limited to areas where hard freezes seldom occur (Saba 1970; Krysan 1986; Elsey 1988, 1989). Saba (1970) reported that banded cucumber beetle adults died after two days exposure to −6°C. However, Elsey (1989) showed that although banded cucumber beetles are intolerant of severe freezing conditions, adults can become acclimatized to cold temperatures and survive in subfreezing temperatures. Elsey (1988) showed that banded cucumber beetle adults are first captured in the Charleston, SC, area in early April, shortly after the last freezing temperatures. This species would not have had time to produce a new generation of adult beetles by early April, which could indicate that at least some adults survive in the Charleston area, even though Charleston averages 32–33 d with freezing temperatures each year (Anonymous 1968, 2004). Therefore, the movement of banded cucumber beetles away from coastal areas where they survived a mild winter could impact sweetpotato growers some distance inland. A better kairomone for baiting Pherocon CRW traps could help further delineate the distribution of this pest in the southeastern United States.

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